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(71) Applicant
The Secretary of State for Defence (United Kingdom), Whitehall, London SW1A 2HB

(72) Inventors
Graham Jolley
Howard Taylor

(74) Agent and/or Address for Service
N A Riddle,
Procurement Executive, Ministry of Defence, Patents 1A4, Room 2014, Empress State Building, Lillie Road, London SW6 1TR

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GB 1094303

(58) Field of search
G1N
H4B

(54) **Alternating current potential drop crack detection**

(57) An alternating current potential drop (ACPD) system for detecting and measuring cracks on the surfaces of electrically conducting materials (10) comprises a constant current AC generator 9 for applying current to material (10), a receiving unit 8 and a self-contained potential drop (PD) transducer unit 7 for attaching directly onto material surface 13. Two sets of detection probes 11, 12 measure the PD over a test area and an uncracked reference area respectively. The receiving unit 8 may be a microprossor controller.

The PD transducer 7 detects the PD on the material surface 13, converts the resulting analogue signal to a digital signal and transmits it to the microprocessor 8 where it is converted to a crack depth value. The signal may be transmitted to the microprocesor 7 via an optical fibre link 14.

The system is relatively immune to interferences and losses and is easily portable for use in the laboratory or in the fi ld.

Fig.2.

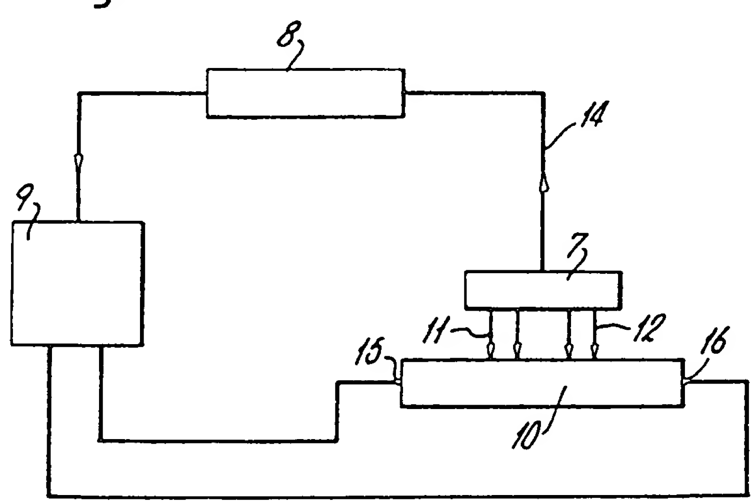

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Fig.1a.

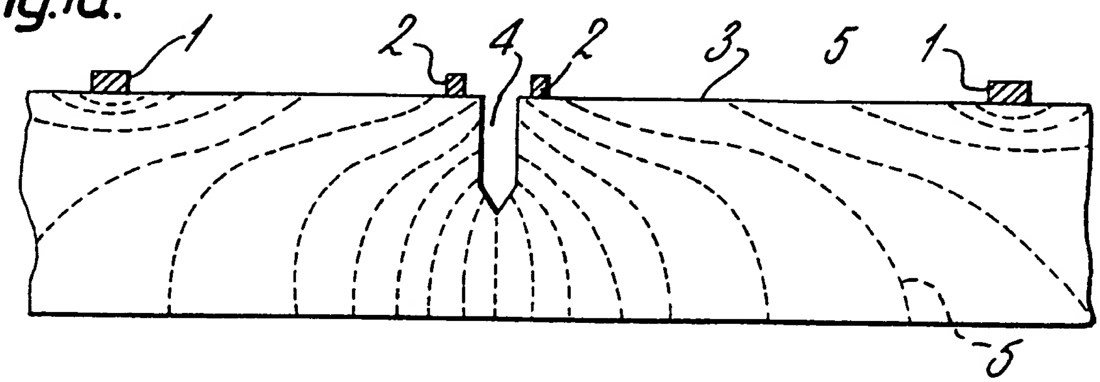


Fig.1b.

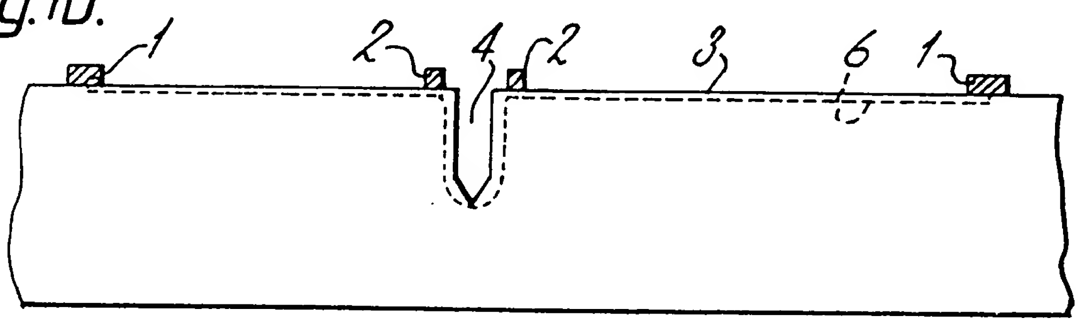
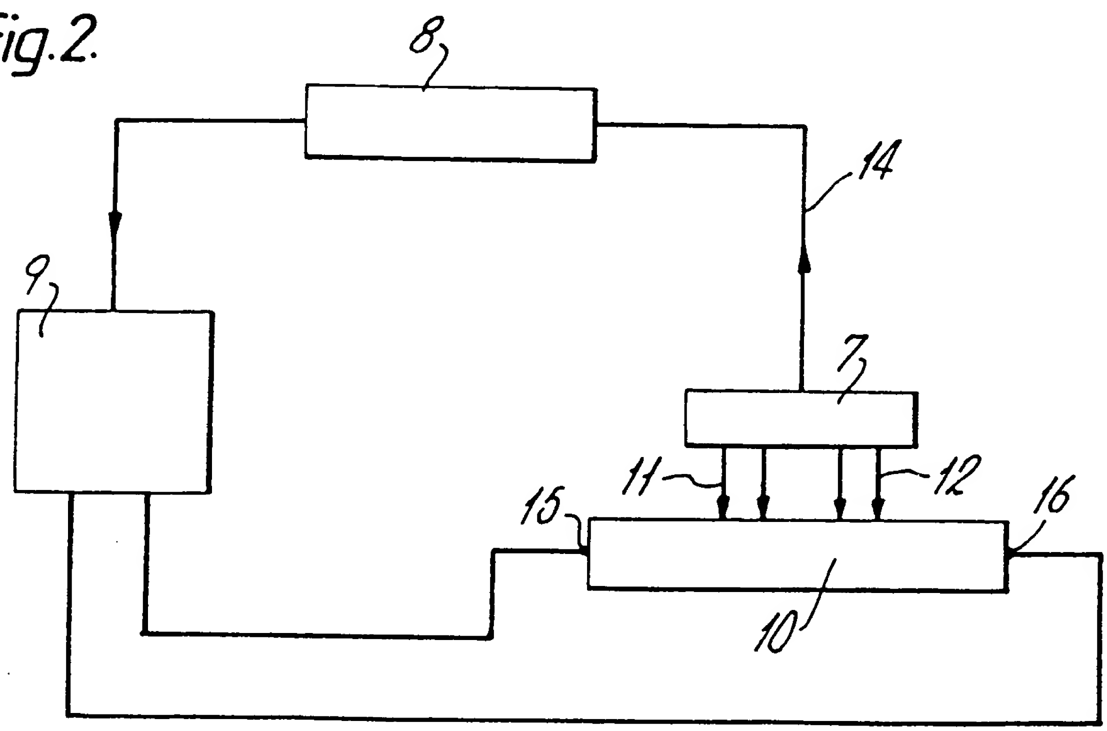


Fig.2.



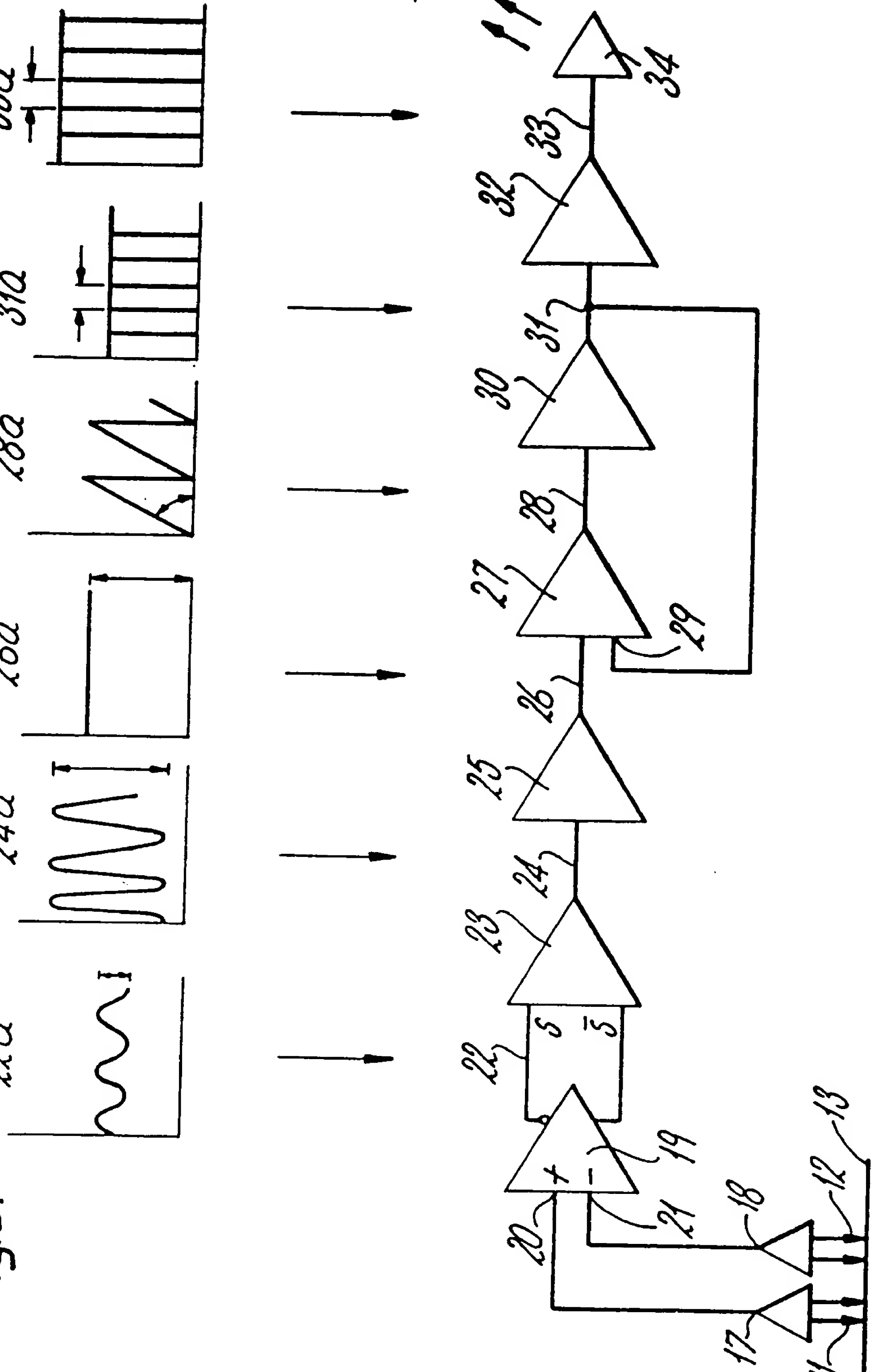

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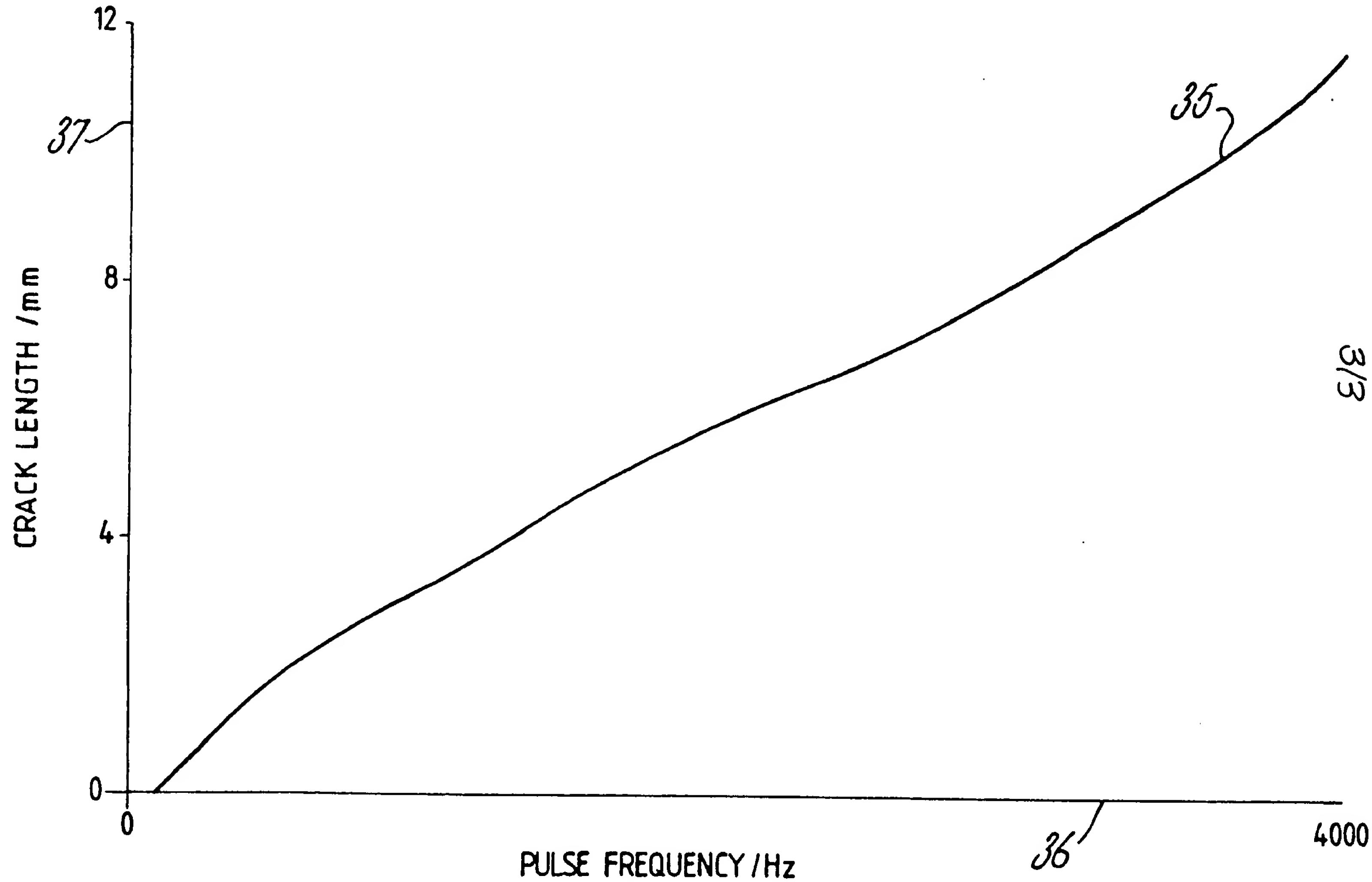
Fig.3.

Fig.4.



SPECIFICATION

Improv ments in r relating to alternating curr nt p tential drop methods f r crack detection and measur ment

The invention relates to methods for detecting and measuring cracks in material surfaces particularly, though not exclusively, for use with metal or other electrically conducting material objects or structures.

Cracks due to fatigue or stress corrosion can occur on the surfaces of objects or structures under stress and the detection, monitoring and sizing of such cracks is of great importance before the cracks lead to failure of the material.

One method used to detect such cracks involves passing an electrical current through a material. This creates an electric field and the potential drop between any two points on the material surface can be measured. Any increase in the potential difference above the normal value will indicate the formation of a crack and the increase can be related to the crack dimensions.

Early attempts to detect cracks using this method involved direct current field measurements. However, this technique is limited by the high currents required on large structures and has little use apart from on small specimens in laboratory conditions.

To overcome this problem alternating current potential drop (ACPD) systems have been developed.

In an alternating current system most of the current flows in a thin skin at the outer surface of the material ie there is a "skin effect". Thus, for a given voltage drop between two points on a surface, a much smaller AC field can be used compared with DC. The "skin depth" varies inversely with frequency.

Because of the skin effect, the measured potential between two detection probes will be approximately proportional to the shortest peripheral distance between the two probes. Thus a crack in the surface will increase the measured potential drop compared to the measured potential drop where there is no crack. Therefore the measurements of potential drop can indicate whether a crack is present on the surface and, if the field can be measured accurately, the measurements can be interpreted in terms of the crack size.

However, any system used for ACPD measurements must be capable of accurately measuring very small voltage differences and prior art ACPD systems have a major disadvantage in that they are susceptible to interferences. Signals may be degraded due to losses or interference if th y are transmitted over any distance and, particularly in th crack initiation stage when any cracks and hence any changes in potential drop are very small, the signals may be degraded to such an extent that no crack information can be obtained.

This problem may be r duced by transmitting the initial signals from the probes on the material surface over the shortest distance possible before processing them.

The object of this invention is to provide an alternating current potential drop system for crack detention and measurement which is relatively immune to losses or interference.

It is a further object of the invention to provide an ACPD system which is lightweight and portable, can be used on a wide variety of different materials, and gives good repeatability and accuracy of results.

The invention provides an alternating current potential drop system for detecting and measuring cracks in the surface of a material wherein the system comprises a constant current AC generator, a receiving unit and self-contained potential drop transducer unit for attaching directly onto a material surface, comprising a converter for changing the PD to a digitally encoded signal.

Advantageously the signal is frequency encoded, in that the output pulse frequency is dependant on the input potential drop.

Preferably the potential drop (PD) transducer unit houses signal detection and processing circuits.

Preferably the PD transducer detects the potential drop on the material surface and converts the resulting analogue signal into a digital signal which can then be transmitted to the receiving unit. This eliminates most of any possible interference.

Preferably all the circuits in the PD transducer are housed on a single printed circuit board.

Conveniently, contact with the material surface may be by spring probes, which ensure good electrical contact and repeatable results and also avoid the problems of spot-welding wires or the unpredictable contact of fixed probes.

Preferably the probes are mounted directly on the printed circuit board and they may conveniently be made of gold-plated phosphor bronze, thus giving low contact resistance and allowing high contact pressure. Conveniently they are able to extend into any notches present on the surfaces from which cracks may propagate.

Preferably there are two sets of detection probes: one set to measure the potential drop between the test points and the other set to provide a reference potential drop over an uncracked area.

Preferably the first stage of the transducer signal processing circuit is a differential output operational amplifier with dual inputs, one input being the PD across the test probes and the other input being the PD across the reference probes. Coveniently one of th inputs is fitted with an offset null facility or trimmer

allowing the utput to be trimmed to z ro.

Preferably the signal from the first set of probes is fed into one pair of inputs in the operational amplifier and the signal from the second set of probes is fed into the alternative inputs. The second signal may then be subtracted from the first. Conveniently the second signal can be attenuated by the trimmer to offset the signal from the first set of probes when no crack is present, thus enabling the initial signal to be zeroed before further processing.

Preferably the PD transducer produces a digital signal suitable for direct computer processing in the form of a series of pulses. Conveniently the pulses are transmitted from the PD transducer to the receiving unit in the form of pulses of light or infra-red radiation along an optical fibre, thereby preventing any possibility of noise or other form of interference affecting the signal.

Preferably the PD transducer unit contains all the stages required to measure the difference between the potential drop at a test point and at a reference point, amplify these signals, convert them to digital form and drive an infra-red or light radiation emitter for transmission of the pulses along the optical fibre to the receiving unit. A fibre optic link for data transmission further reduces possible interference and has many other advantages including: freedom from electromagnetic interference; freedom from cross-talk in multifibre situations; security of signal transmissions; elimination of sparking and fire hazards associated with long electrical wires; the transducer unit can be completely electrically isolated; ground loops can be avoided; the unit can be made low weight but still be strong; and it is possible to have an increased bandwidth with lower losses at higher frequencies than would otherwise be possible.

An optical fibre system can be used to facilitate the transmission of a signal over longer distances than are otherwise possible. It further increases the ACPD system's immunity to noise and also enables a single connection, requiring no reference, to be used between the PD transducer and the receiving unit.

Preferably the signal from the transducer is received by an infra-red or light radiation optical detector as a series of pulses.

Advantageously the whole transducer unit is screened to exclude any electromagnetic interference which might adversely affect the resulting signal.

Preferably the receiving unit comprises a microprocessor controller or microcomputer. The microprocessor converts the r ceived signal into a value related to the depth of any crack which may be present.

Conveniently the microprocessor may also be used to control the current output and frequency of the constant current generator.

This enables th ACPD system to be used to test a wide range of materials including non-magnetic metals such as aluminium alloys and copper alloys. By increasing the frequency the skin effect will be increased, producing a greater potential drop without having to increase the current. Also it is desirable that in use the frequency and current amplitude are optimised.

As the pulse frequency is proportional to the crack depth the microprocessor is advantageously able to count the pulses and thereby determine their frequency so that the value of the crack depth can be deduced.

Conveniently the crack depth is found from a calibration curve of known crack depths against pulse frequencies. The calibration is dependent on the type of material and therefore, for use with a variety of materials, calibration curves should be provided for each material.

Alternatively the microprocessor can be used to calculate the crack depth from known formulae. For example, if the crack depth is x, the voltage across an uncracked surface is V_u and the voltage across a cracked surface is V_c, then

$$x = \frac{V_c - V_u}{2k}$$

where $(V_c - V_u)$ gives the pulse frequency and k is a constant depending on the material.

Conveniently, if the system is being used under laboratory conditions to monitor the effects of loads on certain materials, the microprocessor can also be used to control the load amplitude and frequency of a testing machine when applied to different specimens.

Conveniently the PD transducer may be battery operated, which is practicable because the power consumption may be made low.

Preferably the current inputs to the structure from the constant current generator are positioned so that the voltage distribution across the area of interest is as uniform as possible. In most situations the current inputs can be a long way from the area of interest so that the field becomes uniform around that area. However, if a uniform field cannot be produced, the field in a small area can be examined and any changes from the normal in that area can be used to indicate the presence of a surface crack.

Th current leads can be attached to the structure by a number of means such as sold ring, brazing, spot welding, spring contacts, magnetic contacts, conducting adhesive or screw contacts. For laboratory testing of specimens the best and most reliable method was found to be screw c ntacts. However, in field situations the most convenient and reliable method for any particular set of circum-

stances can be selected.

Because of the variation in sensitivity of the potential difference measurement probes with their position it is preferable, in the case of measurements across a notch, for the probes to be inserted to a position near to the bottom of the notch for maximum sensitivity and repeatability.

Preferably the ACPD system of the invention is capable of being used in the laboratory to examine the behaviour of materials under loads or in the field to detect and measure cracks on a structure without any modifications to the system.

Preferably the PD transducer may be moved easily from one specimen or point on a structure to another. Conveniently it may held in position by a spring clip.

The use of a microprocessor enables a number of refinements to be made, particularly to the laboratory testing. The counter reading the pulses can be started or stopped at any time and so can be synchronised to read only during certain parts of a load cycle eg only on-load to avoid closure effects or on- and off-load to examine the extent of closure effects.

Preferably the current generator unit may be included in the PD transducer unit to produce localised current pulses giving a localised field for measurement by the detection probes.

Preferably low loss optical fibres are used, with glass fibres being generally better than polymer fibres. However, low loss polymer fibres may also be used.

In order that the invention may be more fully understood one embodiment thereof will now be described, by way of example only, with reference to the accompanying drawings of which:

Figures 1(a) and (b) show the different current distributions near a notch in a material sample for the direct current and alternating current methods for crack detection respectively.

Figure 2 is a block diagram of an alternating current potential drop system according to the invention.

Figure 3 is a schematic diagram of a method of implementing a potential drop transducer of the ACPD system, showing the waveforms of a signal at various stages.

Figure 4 is a calibration curve for one material (a high strength steel).

Two conventional methods for crack determination and measurement are schematically shown in Fig. 1. Fig. 1a shows the current distribution for a direct current input. The current inputs 1 are at a distance from the potential drop measurement probes 2 which are positioned on a surface 3 of a material. The probes 2 are sited on either side of a notch 4 from which a crack may propagate. Equipotential lines 5 indicate the field distribution.

Fig. 1b illustrates the "skin eff ct" present with an alternating current input. The current inputs 1 ar again positioned at a distance from the measurement probes 2 on either side of the notch 4 but here the current follows a path 6 close to the surface 3 of the material.

The present invention makes use of the AC effect shown in Fig. 1b which has a particular advantage over the DC method of Fig. 1a in that most of the current flows near to the material surface, enabling a lower current to be used to produce a given voltage drop.

Referring now to Fig. 2, a block diagram of the ACPD system is shown. The system comprises three main components: a potential drop (PD) transducer 7; a microprocessor controller 8; and a constant current generator 9.

The PD transducer 7 is attached to a specimen or structure 10 which is to be tested. Two sets of measurement probes 11, 12 contact the surface 13 of the structure 10. The probes 11 measure the potential drop across a test area and the probes 12 measure the potential drop across an uncracked area to give a reference voltage. The difference between the potential drop measured by the probes 11 and the probes 12 is then converted by the transducer 7 to a digital signal which is then transmitted along an optical fibre 14 to the microprocessor 8 where it is converted into a value which can be equated to the depth of any crack which may be present between the two probes 11.

The transducer 7 contains all the stages required:

a. to measure the potential drop at the test point and the reference point;

b. amplify the difference signals;

c. convert them to digital form; and

d. transmit a signal along the optic fibre 14 to the microprocessor 8.

By constructing the device, such that the signal processing circuitry is adjacent to the probes, circuit loops which are a source of noise are reduced and the signal to noise of the device can be maximised.

The current generator 9 is a square wave constant current source which passes a current through the structure 10 via input and output contacts 15, 16. The microprocessor 8 can be used to control the current output and frequency of the current generator 9 so that the current amplitude and frequency can be optimised for any particular circumstances. Preferably a frequency of about 10kHz is used.

Referring to Fig. 3, the PD transducer 7 can be implemented as a six-stage signal conditioner. The signals from the two sets of probes 11, 12 on the surface 13 are amplified by differential operational amplifiers 17, 18 and passed to the first stage of the signal conditioning circuits, a wide-band differential amplifier 19. The amplifier 19 has two-channel differential inputs 20, 21, a differential

output stage 22 and a full power bandwidth of 50 MHZ. One of the inputs 20 is taken from the defect or crack at probes 11 and the other input 21 is taken fr m the reference point at probes 12. The output 22 consists of the difference between the two input signals 20, 21. The output' 22 is passed to the second stage which is a gain stage consisting of a single, low noise, low distortion differential operational amplifier 23, with a bandwith of 150 KHz, which acts on signal S at the output 22 and $\bar{S}$ the antiphase component. The signal from the differential output 22 of the amplifier 19 is amplified to a level of the same order as the supply voltage. The output 24 of the amplifier 23 is passed to the third stage which is a peak detector 25 producing an output 26 of a level proportional to the amplitude of its input signal 24. The signal 26 is passed to the fourth stage, an integrator 27 with an output 28 having a rate of change proportional to the level of the input 26. The integrator 27 has a second input 29 for resetting the output 28 to zero.

The signal 28 is passed to the fifth stage 30. When the input 28 of this stage 30 reaches a predetermined level the output 31 pulses. The output 31 is connected back to the reset input 29 of the previous stage 27. Stage 5 and Stage 4 combine to form an analogue-to-digital converter.

The final stage is a unity gain current booster 32 to provide pulses 33 for an infra-red light emitting diode 34. The LED 34 is narrow beam and high intensity and provides an infra-red signal for transmission along the optical fibre 14 (Fig. 2).

The waveforms of the signals at each output stage 22, 24, 26, 28, 31, 33 are shown graphically at 22a, 24a, 26a, 28a, 31a and 33a respectively.

Referring to Fig. 4, the calibration curve 35 for a high strength steel is shown. Changes in pulse frequency 36 are shown against corresponding changes in crack depths 37. It can be seen that as the crack depth increases and the potential drop increases, so the pulse frequency increases. Calibration curves for other materials are similar.

One or more calibration curves appropriate to materials to be tested are stored for use by the microprocessor. After detection and measurement of a crack by the system the microprocessor can be arranged to produce a visual and/or audio indication of the condition of the material sampled.

Although the system has been described using a fibre optic connector between the transducer unit and the microprocessor unit it may be advantageous under certain circumstances to omit the infra-red emitt r and use an electrical wire connection carrying electrical pulses from the transducer unit to the microprocessor.

A further cricuit modification (not shown) has been found to improve the signal strength. A transformer is connected between the probes and the electrical circuitry to provide an impedance match and thereby increase the signal for processing.

The ACPD system of the invention has many advantages over prior art systems in that: it is immune of interference; it has low losses; it is lightweight and easily portable; it can easily be moved from one test point to another; it can be used on any electrically conducting material; it gives good repeatability and accuracy of results; it can be used in the laboratory and in the field; it combines low weight with high strength.

It also has several other advantages over prior art systems such as:

a. The receiving unit is remote from the transducer unit and non-specialised receiving equipment can be used—standard data loggers or microcomputers can be used. This has the additional advantage in that the output information does not have to be specialised.

b. The receiving unit may be a programmable microcomputer so that changes for different materials or conditions can be programmed in so that ACPD system user can indicate the conditions and the programme will make any changes required for correct measurement of crack depth.

c. The transducer is a small, compact unit which is easily portable.

d. The frequency of the current generator output can be varied so the frequencies can be scanned and the changes in apparent crack depth examined. This is particularly useful if there may be branched or jagged cracks as in these cases it is usually the depth of the crack rather than the total crack length which is of interest. If a shorter crack length is recorded at low frequencies than at high ones the crack is probably branched or jagged and low frequency measurements may be used to predict the crack depth rather than its overall length.

e. The possibility of using either a calibration method or a calculation method for finding crack depths from the potential drop is useful. The calibration method is accurate but initially very time-consuming in that each different material has to be examined to produce its calibration curve. The calculation method is easier but not so accurate and requires extra signal processing. It also requires some calibration as there is a constant term which is different for each material. A "material constant" can be programmed in so that the system can be changed from material to material very easily. There is no difference in operation between either method for the end-user so the method used may be decided on cost and accuracy requirements.

CLAIMS

1. An alternating current potential drop (ACPD) system for detecting and measuring

cracks in the surface of a material comprising:

a. a constant current AC generator;

b. a receiving unit; and

c. a self contained potential drop (PD) transducer unit for attaching directly onto a material surface comprising a convertor for changing the PD to a digitially encoded signal for transmission to the receiving unit.

2. An ACPD system according to Claim 1 wherein the signal is frequency encoded in that the output pulse frequency is dependent on the input potential drop.

3. An ACPD system according to Claim 1 or Claim 2 wherein signal detection and processing circuits in the PD transducer are housed on a single printed circuit board.

4. An ACPD system according to any one preceding claim wherein there are provided on the transducer unit two sets of detection probes: one set to measure the potential drop between test points and the other set to provide a reference potential drop over an uncracked area.

5. An ACPD system according to Claim 4 wherein contact with the material surface is by spring probes.

6. An ACPD system according to Claim 4 or 5 wherein the first stage of the transducer signal processing circuit is a differential input operational amplifier with one input being the potential drop across the test probes and the other input being the potential drop across the reference probes.

7. An ACPD system according to claim 6 wherein transformer impedance matching is used between the probes and the signal processing circuitry.

8. An ACPD system according to Claim 6 or 7 wherein one of the inputs is fitted with an offset null facility or trimmer allowing the output to be trimmed to zero.

9. An ACPD system according to Claim 8 wherein the pulses are transmitted from the PD transducer to the receiving unit in the form of pulses of light or infra-red radiation along an optical fibre.

10. An ACPD system according to any one preceding claim wherein the transducer unit is screened to exclude electromagnetic interference.

11. An ACPD system according to any one preceding claim wherein the receiving unit comprises a microprocessor controller.

12. An ACPD system according to Claim 11 wherein the microprocessor converts the received signal into a signal related to the depth of any crack which may be present.

13. An ACPD system according to Claim 11 or 12 wherein the microprocessor is used to control the output current amplitude and frequency of the constant current generator.

14. An ACPD system as claimed in any one preceding claim wherein the frequency of the constant current generator is selected to be substantially 10kHz.

15. An ACPD system as hereinbefore described with reference to Figs. 2 and 3 of the drawings.

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